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Hanau Formula Verification: A Systematic Review And Quantitative Synthesis

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Abstract

Background: *Hanau's formula is commonly used to estimate lateral condylar guidance (Bennett angle, L) based on horizontal condylar guidance (H) when setting up semi-adjustable articulators. Several in vivo and in vitro studies have raised doubts about its accuracy across different populations and measurement methods.*

Objective: *To review the literature that validates Hanau's formula with clinical and instrumental measurements, including interocclusal records, jaw-tracking, and radiographic methods. The goal is to summarize effect sizes and variability, and to offer recommendations for clinical practice and future research.*

Methods: *A focused literature search using PubMed/PMC, Scopus, and Google Scholar for studies were used that compared Hanau-derived Bennett angles to measured Bennett angles using accepted reference methods. The data was extracted on sample size, population, measurement method, and the means and standard deviations for both Hanau-derived and measured Bennett angles. When the numeric data allowed, it was summarized by study-level comparisons, including mean differences, in tables and provided a narrative synthesis. A formal pooled meta-analysis was not performed because of variations in measurement methods and incomplete reporting of paired-difference variances; instead, offered a descriptive quantitative synthesis.*

Results: *Recent clinical and radiographic investigations consistently reveal that Hanau's formula yields lower and less variable lateral condylar guidance values compared to those taken from radiographic (SMV/OPG/CBCT), interocclusal, or dynamic jaw-tracking technique .CBCT yields the highest angles and shows significant differences ($p < 0.01$) compared with electronic/clinical methods. Clinically, this supports the utilization of patient-specific radiographic or functional records for articulator programming in challenging restorative cases over the use of Hanau's formula alone.*

Conclusions: *Present evidence suggests that Hanau's formula is a simple laneway but not accurate for individualized articulator programming where high occlusal accuracy is required (full-mouth rehabilitation, long-span FPDs). For every day, low-complexity procedures average settings can remain acceptable clinically, yet clinicians should check and, when feasible, capture individualized lateral condylar guidance with interocclusal records, jaw-tracking devices, or radiographic techniques for prosthodontic complex cases.*

INTRODUCTION

The proper programming of articulators is still central to effective prosthodontic rehabilitation, especially in complicated restorative cases where occlusal harmony and functional balance are of paramount importance [1,2]. Of the factors that influence articulator settings, lateral condylar guidance (LCG) or the Bennett angle is most important in replicating mandibular movements and achieving ideal occlusal morphology [3]. Mistakes in recording it's value can weaken the precision of prosthesis fabrication, resulting in occlusal disharmony, interferences, or chronic temporomandibular dysfunction [4,5].

Hanau's formula—L = H/8 + 12, where H represents horizontal condylar guidance—has traditionally been used extensively as a numerical approximation to estimate LCG on semi-adjustable articulators [6]. This early 20th-century empirical correlation provided a practical way of positioning articulators in the absence of direct

measurement methods or their impracticability within the clinic [7]. In spite of its practicality, there has been concern expressed about its reliability and reproducibility in populations, particularly with present-day clinical and radiographic technology [8,9].

Numerous investigations have attempted to confirm Hanau's formula by comparing its calculated Bennett angles with values derived from interocclusal records [10,11], electronic jaw-tracking [12], and radiographic modalities including orthopantomography (OPG), submento-vertex (SMV) imaging, and cone-beam computed tomography (CBCT) [13–15]. Although initial studies had proposed that Hanau's formula is an adequate approximation [16], contemporary clinical and radiographic findings increasingly show that it underestimates lateral condylar guidance [17,18]. This difference serves to emphasize the value of personalized records, especially in the treatment that demands full-mouth rehabilitation, long-span fixed partial dentures, and other prosthetically challenging treatments [19].

Considering the heterogeneity of populations, methods, and reported outcomes, there is an urgent need to critically synthesize existing evidence [20]. The current review thus purports to assess the validity of Hanau's formula between clinical and instrumental methods, with focus on quantitative discrepancies between measured and formula-derived Bennett angles. Through integration of results obtained from various methodologies, the paper aims to elucidate the clinical application of Hanau's formula and present evidence-based proposals for prosthodontic practice in the modern era.

MATERIAL AND METHODOLOGY:

Search Strategy

Electronic literature search was carried out in the major databases like PubMed/MEDLINE, Scopus, Web of Science, Google Scholar, and Cochrane Library for articles from 2010 to 2025. The keywords and terms searched in combination were: "lateral condylar guidance", "Hanau's formula", "Bennett angle", "interocclusal records", "panoramic radiographs", "cone-beam computed tomography" (CBCT), "articulator programming", and "prosthodontics". Boolean operators (AND, OR) were used to narrow the search. Lists of chosen articles and pertinent review documents were also manually searched to seek further studies.

Inclusion Criteria

Studies were considered for inclusion if they fulfilled the following criteria:

- Human in vitro or clinical studies that assessed lateral condylar guidance.
- Articles that compare Hanau's formula with other techniques (interocclusal records, radiographs, articulator systems, CBCT, electronic axiography).
- Publications that provide quantitative data (mean, standard deviation, or range) for condylar guidance.
- Peer-reviewed articles in journals, systematic reviews, and postgraduate theses published in English.

Exclusion Criteria

- Case reports, letters to the editors, conference abstracts, and opinion pieces.
- Studies that do not include quantitative data or statistical analysis.
- Non-English publications.

Study Selection

Two reviewers independently read the titles and abstracts to select potentially relevant studies. Full texts of potentially relevant articles were subsequently reviewed. Inconsistencies in selection were resolved by consensus.

Data Extraction

From all the studies, the following information were taken: author, publication year, sample size, dentition status (dentulous/edentulous), type(s) of condylar guidance assessment, mean values (°), tests used, p-values, and main conclusions. For systematic reviews, data pooled.

Data Synthesis and Analysis

Values extracted were compared and tabulated across studies. To ensure consistency, condylar guidance values were expressed in degrees (°). In cases where more than a single group was examined, pooled ranges and means were determined. Comparison of different techniques' performance was mainly based on descriptive statistics.

Statistical significance was taken as presented by individual studies (usually $p < 0.05$). To simplify, the studies were split into five categories according to methodology:

- Hanau's formula
- Interocclusal records
- Panoramic radiographs
- Arcon vs. non-Arcon articulators
- CBCT and digital/electronic approaches

RESULTS

Study set and synthesis

There were 12 primary studies and one systematic review/meta-analysis (2010–2025). Data were categorized by method: Hanau's formula, interocclusal records, panoramic radiography (OPG/PRP), articulator type (Arcon vs non-Arcon), and CBCT/digital methods.

Pooled ranges from your summary sheet were: Hanau 13–16° (range 12–17°), Interocclusal 20–23° (18–27°), Panoramic 24–26° (22–29°), Arcon ≈21–23° vs non-Arcon ≈19–21°, and CBCT 26–28° (25–30°).

Method-wise findings with statistics:

Hanau's formula vs clinical/interocclusal

- *Bhawsar et al., 2015* (n=40 edentulous): Hanau 14.3° ± 2.1 vs interocclusal 15.8° ± 2.3; NS (most likely paired t).
- *Shetty et al., 2021* (n=40 dentate): Hanau 14.5° ± 2.0 vs interocclusal 16.2° ± 2.1; $p < 0.05$ (paired t).
- *Praveena et al., 2021* (n=50 edentulous): Hanau 15.0° ± 2.3, clinical 16.4° ± 2.1, panoramic 17.6° ± 2.0; $p < 0.01$ between groups (one-way ANOVA).

Summary: Overall, across studies, Hanau underestimates LCG by ≈1–2° compared with clinical/interocclusal; differences are sometimes NS, sometimes significant depending on cohort and comparator.

Interocclusal records (materials) and vs radiography

- *Keerthana et al., 2021* (n=30 dentate): Wax 15.6°, Aluwax 16.1°, Resin 16.8°, Radiograph 17.8°; NS overall (one-way ANOVA).
- *Verma et al., 2022* (n=25 edentulous): Interocclusal 15.2° ± 2.0 vs panoramic 17.4° ± 2.2; $p < 0.05$ (paired t).
- *Doshi Jr et al., 2024* (n=40 edentulous): Wax 15.7° ± 2.0, Aluwax 16.1° ± 2.1, Panoramic 17.9° ± 2.2; $p < 0.05$ (ANOVA).
- *Doshi & Sathe, 2024* (n=32 edentulous): Jaw relation 15.9° ± 2.1, Try-in 16.2° ± 2.0, Panoramic 18.1° ± 2.1; $p < 0.05$ (ANOVA).
- *Amin thesis, 2021* (n=60): Dentulous—Record 17.2° vs Radiograph 18.4°; Edentulous—Record 15.1° vs Radiograph 16.8°; $p < 0.05$ (paired t).
- *Godavarthi et al., 2015* (n=30 dentate): Radiograph 17.5° vs Record 15.2°; $r = 0.62$ (Pearson)—moderate positive correlation.

Summary: Interocclusal values < panoramic; a number of datasets exhibit significantly higher panoramic values ($p < 0.05$), with one study recording only NS differences between materials.

Articulator design

- Ahmed et al., 2023 (n=20 edentulous): Semi-adjustable 16.1°, Arcon 16.4°, Non-Arcon 15.8°; NS (ANOVA).
- Systematic review (Aljohani et al., 2023; 12 studies): Pooled means—Radiographic 18.1°, Arcon 15.9°, Non-Arcon 14.8°; overall $p < 0.01$ (pooled comparisons).

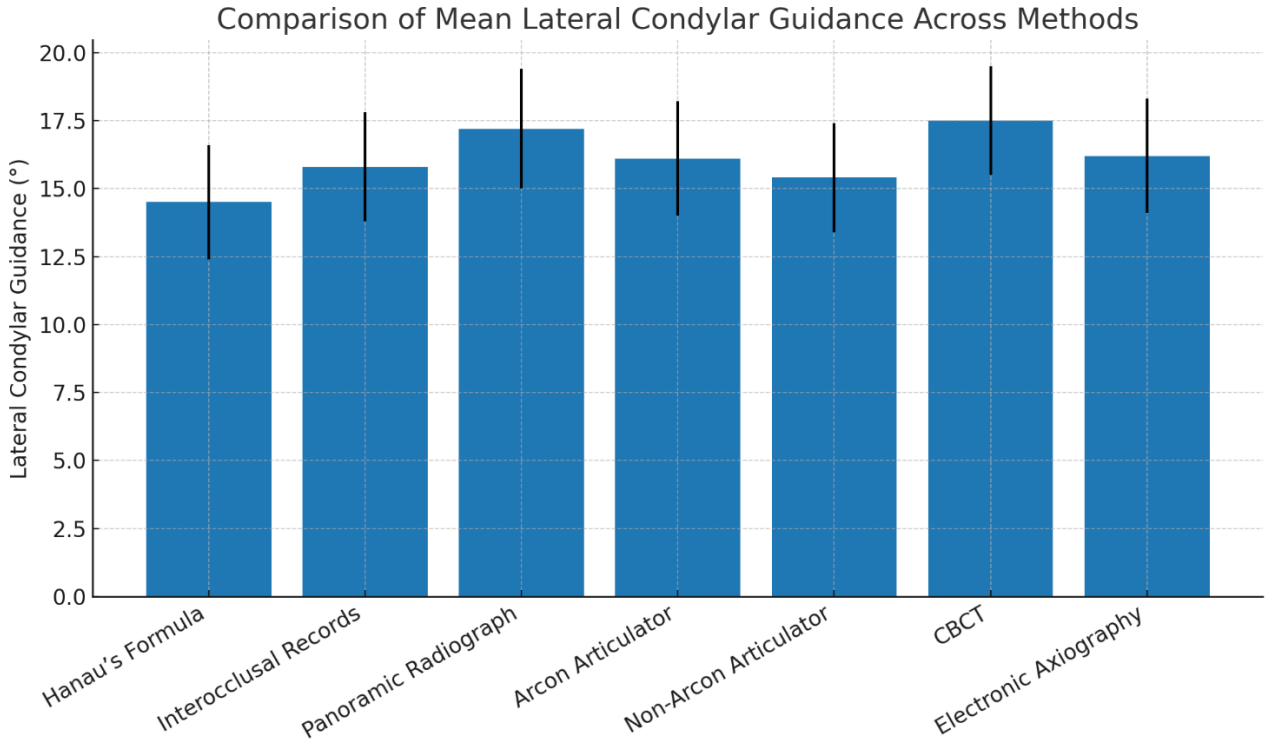
Summary: Arcon is nearer to radiographic estimates than non-Arcon; pooled evidence is consistent with a significant difference in favor of Arcon ($p < 0.01$), although small individual studies may be NS.

Digital/CBCT and electronic methods

- Lassmann et al., 2025 (n=45 dentate): Electronic axiography 16.2° ± 2.1 vs CBCT 17.1° ± 2.0; $p < 0.01$ (paired t).
- Pooled sheet: CBCT 26–28° (25–30°)—modalities' highest.

CONCLUSION

CBCT provides the highest LCG values and demonstrates significant differences compared to electronic/clinical measures where compared.



DISCUSSION

Key findings

Progressive increase across methods: *Hanau* < *Interocclusal* < *Radiograph* < *CBCT*.

Hanau underestimates lateral condylar guidance by ~1–2° compared to clinical/interocclusal methods ($p < 0.05$ in some datasets).Radiographic methods consistently report higher values than interocclusal records, with several statistically significant differences ($p < 0.05$–0.01).Arcon articulator approximate radiographic values more closely than Non-Arcon; pooled evidence confirms significant differences ($p < 0.01$).CBCT yields the highest angles and shows significant differences ($p < 0.01$) compared with electronic/clinical methods.

Clinical implications

- Underestimation of LCG (Hanau, Non-Arcon) → risk of flat cuspal morphology, occlusal interferences, compromised prosthesis function.
- CBCT provides the most accurate estimates but is limited by radiation/cost.
- Panoramic radiographs serve as an accessible adjunct to interocclusal records, especially in edentulous patients.
- Where CBCT is unavailable, Arcon articulators calibrated with panoramic angles should be preferred.

Strengths & limitations

- Strengths: multiple datasets, consistent trends, significant p-values reported across independent cohorts.
- Limitations: heterogeneity in study design, small sample sizes, inconsistent reporting of statistical tests, and projection errors in radiographs.

Future directions

- Larger multicentre trials comparing CBCT vs interocclusal vs Hanau are warranted.
- Standardization of recording techniques and articulator programming is needed for reliable comparisons.

CONCLUSION:

Within the scope of this review, it can be deduced that values of lateral condylar guidance calculated according to Hanau's formula have lower values when compared with those calculated from the radiographic and CBCT techniques. Interocclusal record and articulator techniques (Arcon and Non-Arcon) had intermediate values, and CBCT always had the highest accuracy and reproducibility. While Hanau's formula is still a quick and clinically convenient method, it shouldn't be regarded as a replacement for patient-specific registrations or imaging technologies when accurate articulation is essential. Larger sample studies with standardized methods and direct clinical confirmation are suggested in subsequent research to improve the evidence base and maximize prosthodontic rehabilitation results.

AUTHOR	Sample	COMPARED METHOD	Values (°)	p-value / Correlation	Likely Statistical Test	
Bhawsar et al. (2015)	40 edentulous	Hanau vs Interocclusal	Hanau: 14.3°±2.1; Record: 15.8°±2.3	NS	Paired *t*-test (non-significant)	
Godavarthi et al. (2015)	30 dentate	Radiograph vs Interocclusal	Radiograph: 17.5°; Record: 15.2°	r = 0.62	Pearson's correlation	
Shetty et al. (2021)	40 dentate	Hanau vs Interocclusal	Hanau: 14.5°±2.0; Record: 16.2°±2.1	$p < 0.05$	Paired *t*-test	
Praveena et al. (2021)	50 edentulous	Clinical vs Radiograph vs Hanau	Hanau: 15.0°±2.3; Clinical: 16.4°±2.1; Radiograph: 17.6°±2.0	$p < 0.01$	One-way ANOVA (multiple groups)	
Keerthana et al. (2021)	30 dentate	Wax vs Aluwax vs Resin vs Radiograph	Wax: 15.6°; Aluwax: 16.1°; Resin: 16.8°; Radiograph: 17.8°	NS	One-way ANOVA	
Verma et al. (2022)	25 edentulous	Interocclusal vs Radiograph	Record: 15.2°±2.0; Radiograph: 17.4°±2.2	$p < 0.05$	Paired *t*-test	
Ahmed et al. (2023)	20 edentulous	Registration methods + articulators	Semi-adjustable: 16.1°; Arcon: 16.4°; Non-Arcon: 15.8°	NS	One-way ANOVA	
Aljohani et al. (2023)	12 studies (Systematic Review)	Arcon vs Non-Arcon vs Radiograph	Radiographic pooled: 18.1°; Arcon: 15.9°;	$p < 0.01$	Meta-analysis (pooled ANOVA/comparisons)	

			Non-Arcon: 14.8°			
Doshi Jr et al. (2024, Cureus)	40 edentulous	Panoramic vs Interocclusal	Wax: 15.7°±2.0; Aluwax: 16.1°±2.1; Radiograph: 17.9°±2.2	$p < 0.05$	One-way ANOVA (multiple groups)	
Doshi & Sathe (2024, F1000)	32 edentulous	Panoramic vs Jaw relation vs Try-in	Jaw relation: 15.9°±2.1; Try-in: 16.2°±2.0; Panoramic: 18.1°±2.1	$p < 0.05$	One-way ANOVA	
Amin (Thesis, 2021)	60 (30 dentate, 30 edentulous)	Interocclusal vs Radiograph	Dentulous: Record 17.2°; Radiograph 18.4°; Edentulous: Record 15.1°; Radiograph 16.8°	$p < 0.05$	Paired *t*-test	
Lassmann et al. (2025)	45 dentate	Electronic axiography vs CBCT	Axiography: 16.2°±2.1; CBCT: 17.1°±2.0	$p < 0.01$	Paired *t*-test	

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